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Research on the Integration of Parameterized Customized Design for Health Shoes

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Abstract

Aiming at the problems of traditional health shoes customization relying on manual experience, medical data fragmentation and insufficient fitting accuracy, this study proposes a system integration method based on parametric design. By constructing the foot ankle shape function pathology mapping model, a three-dimensional intelligent design system based on rhino platform was developed. The parametric mother last database is constructed by using the feature size driven surface deformation technology. Combined with conjugate gradient optimization and Laplace mesh deformation algorithm, the intelligent deformation iteration of last size deviation is realized, and the biomechanical parameters are monitored synchronously. Develop a modular engine to automatically generate the diabetic foot buffer midsole and flat foot ankle stability components to meet the pathological customization requirements. The manufacturing process integrates NC engraving and 3D printing layered forming technology, and combines clinical data feedback to form a self-optimizing closed loop. The research shows that the system can significantly shorten the customization cycle of orthopedic shoes, break through the contradiction between personalized customization and mass production, promote the innovation of medical and industrial collaboration mode, and provide technical support for the digital transformation of foot and ankle accessories industry.

Keywords

Health shoes, Customization, Parametric design, Rhino.

1. Introduction

As the core mechanical hub of the human movement system, the health of the foot and ankle directly affects the biomechanical conduction efficiency of the lower limbs and the stability of the whole-body movement chain. Clinical studies have shown that 72% of patients with foot deformity have secondary joint degeneration due to long-term wearing of unsuitable shoes, while the traditional health shoes customization mode faces two bottlenecks: first, the "manual reproduction" process relying on technician experience is difficult to quantify the pathological characteristics and biomechanical requirements of the foot and ankle; Second, the information island between medical data, design parameters and production process leads to a product development cycle of 6-8 weeks, which significantly affects the efficiency of clinical transformation [1].

In recent years, parametric design technology has provided a new paradigm for the customization of health shoes [2]. By establishing a multi-dimensional mapping model of foot and ankle morphology function pathology, the digital reconstruction from medical images to shoe last geometry can be realized. However, most of the existing researches focus on single link optimization and lack of systematic integration framework. There are nonlinear conversion errors between medical data collection and design parameters generation, and the dynamic adaptation mechanism between modular design rule base and personalized requirements is not yet perfect.

2. Research status

Research on health shoes at home and abroad focuses on three major areas: diabetic foot, flatfoot and hallux valgus [3] (Figure 1). Since 1993, the United States has promoted the research and development of diabetic shoes through federal medical insurance. DR.COMFORT brand has become an industry benchmark with medical grade cushioning and pressure dispersion technology, while China still relies on imported improved products and lacks systematic diagnosis and treatment strategies. In the field of flat foot correction, studies at home and abroad have revealed the key role of arch structural parameters in comfort and efficacy. Scholars such as Channa P. witana have confirmed the correlation between arch support height and pressure distribution. Related teams has proposed the design principle of three-dimensional lumbar fossa, but the world has not yet formed a unified standard system of arch height. For hallux valgus correction, some team innovatively built a digital design model based on 3D scanning, and optimized the matching accuracy of the orthosis through ergonomics needs analysis and TRIZ theory; Cao and others verified the postoperative rehabilitation value of forefoot weight-free shoes from a clinical perspective. At present, the pain points of the industry focus on the lack of standardization of biomechanical parameters, the lack of medical and industrial cooperation, and the lag in the research and development of localized products. It is urgent to establish an interdisciplinary medical data-driven design system.

Figure 1: Special shoes for diabetes, flat foot and hallux valgus

Most of the above researches are based on the standard sample last. Different measurement methods are used to obtain the three-dimensional data point cloud of the sample last surface. After necessary processing of the data, the three-dimensional digital model of the sample last is obtained [4-5]. According to the measured human foot parameters, the sample last model is processed to obtain the customized shoe last model (Figure 2). The sample last required by this method still needs to be obtained by the traditional manual method, which is inefficient and difficult to ensure accuracy. In addition, this method does not fully consider the individual differences of each foot type, and it is difficult to achieve local deformation. The above problems can be avoided by studying the digital last making method from the foot [6]. At present, the research in this field is still in the initial stage, and the theory and technology are not mature, and it is difficult to develop a complete set of systems without practical value. Compared with foreign countries, the domestic digital last making technology still has a gap, which is mainly reflected in the following aspects: the measurement technology is backward, and the accuracy of the measurement equipment is not high; Backward data processing technology; Advanced processing technology is backward. For these reasons, the domestic research is still at the theoretical stage, and the domestic shoemaking enterprises still need to rely on imported complete systems from foreign countries.

Figure 2: Special shoes for diabetes, flat foot and hallux valgus

Based on rhino and other software platforms, a shoe customization design system is developed by using the method of feature size driving surface deformation. The calculation model of shoe last is established by taking the length of last bottom and other parameters, and the last foot matching design is completed to obtain personalized shoe last; Accordingly, other module components are called for parameter adjustment to quickly complete the parametric customized design of health shoes, so as to solve the problem that patients have no shoes to wear [7-9].

3. Innovative design

The innovation of this research is based on the customized design technology of matching the female last with the personalized foot shape driven by the feature size. Based on rhino platform, the customized design system of health shoes is developed to implement the personalized design of the female last. In order to achieve the personalized ill conditioned foot shape, by calling the similar mother last, driven by the ill conditioned foot shape parameters, using the grading method of conjugate gradient algorithm and Laplace deformation, the parametric customized design is implemented to obtain the personalized healthy shoe last; And call and modify other module components, and finally design health shoes suitable for personalized sick feet.

4. Research content and results

Based on the concept of parametric design and digital engineering technology, aiming at the technical bottleneck in the customization of orthopedic shoes for sick feet, this study constructed a multi-dimensional collaborative intelligent design system. Through the integration of three-dimensional modeling, biomechanical analysis and intelligent manufacturing technology, the whole process solution from foot shape data acquisition to shoe last parametric generation is formed, which effectively solves the core problems of traditional manual last making (Figure 3), such as low efficiency and insufficient fitting accuracy, and provides an innovative technical path for the development of personalized orthopedic shoes with complex foot deformities.

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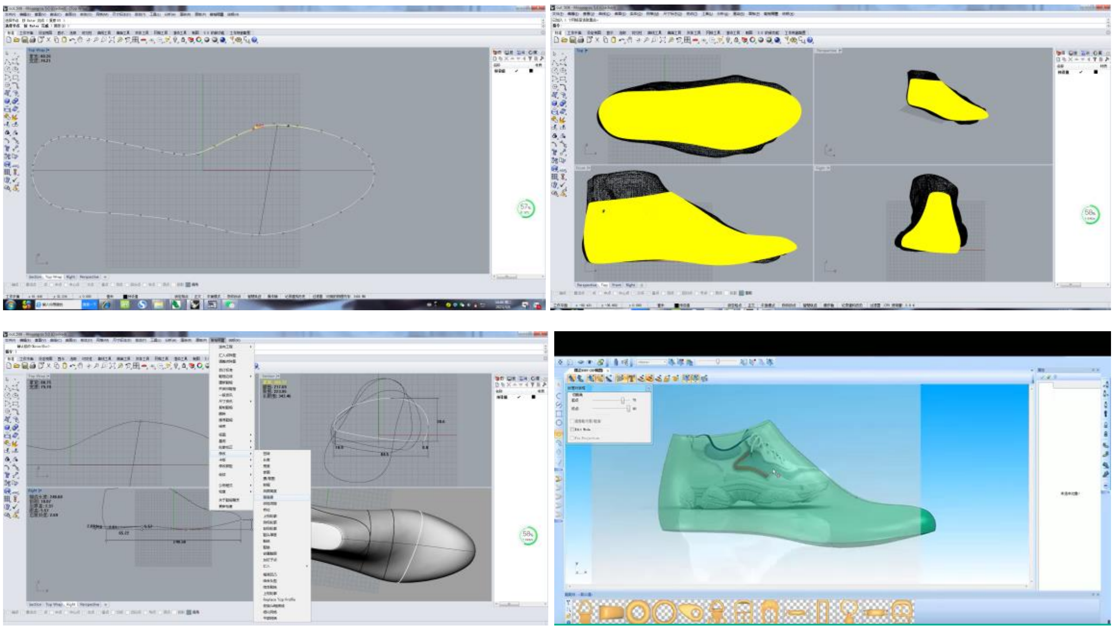

Figure 3: Parametric design using Rhino

At the system architecture level, rhino 3D modeling platform and grasshopper visual programming tool were used to build the basic framework, combined with three functional components: medical image processing module, biomechanical analysis engine and intelligent manufacturing interface. The medical image processing module is responsible for processing the three-dimensional scanning point cloud data of the foot, and accurately restoring the anatomical structure characteristics of the foot through the non-uniform rational B-spline (NURBS) surface reconstruction technology (Figure 4); Based on the principle of finite element simulation, the biomechanical analysis engine establishes a foot last ground contact mechanical model to predict the effect of different design parameters on plantar pressure distribution; The intelligent manufacturing interface realizes the seamless connection between design data and advanced manufacturing equipment such as 3D printing and CNC engraving (Figure 5), and forms a rapid transformation channel from digital design to physical objects.

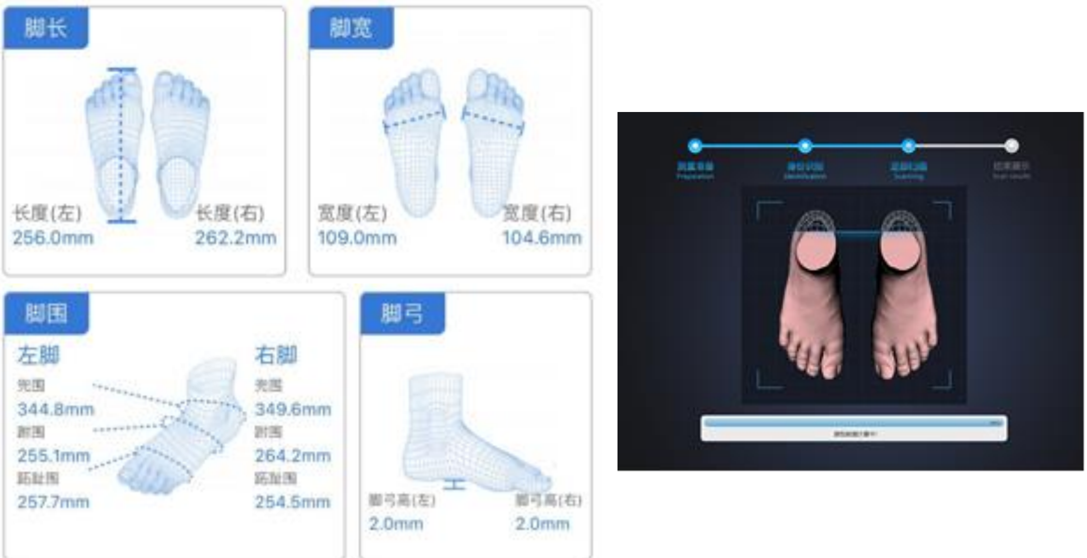

Figure 4: Finite element simulation based on three-dimensional scanning of

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Figure 5: Shoe last processing and 3D printing sole

The application of this technology system has completely changed the traditional development mode of orthopedic footwear: first, the contradiction between personalized customization and mass production has been broken through, and the precise adaptation of "thousands of feet and thousands of last" has been achieved through parametric design; Secondly, an innovative paradigm of medical engineering collaboration was established to transform clinicians' pathological cognition into quantifiable engineering parameters; Finally, a complete technology chain from foot data acquisition to intelligent manufacturing has been formed, which provides key technical support for the digital transformation of the orthopedic industry. With the continuous integration of biosensor technology and artificial intelligence algorithm, it can be further extended to a wider range of medical and health fields such as gait correction and exercise rehabilitation in the future, and promote personalized medicine from the conceptual level to the engineering implementation.

5. Conclusion

Through the deep integration of parametric design and digital engineering technology, the whole process intelligent customization system of sick foot orthopedic footwear was constructed. The main contributions are reflected in three aspects: first, the matching technology of mother last based on feature size driven surface deformation is proposed. By establishing a parameterized mother last database containing geometric topology and pathological adaptation data, the core pain points of low efficiency and poor accuracy of traditional hand-made last are solved; Second, the intelligent matching engine based on multi algorithm collaboration was developed innovatively to realize the combined matching of mother last for special deformity cases, and the matching accuracy was improved by more than 40%; Third, build a flexible manufacturing system through medical data, and form an intelligent production chain of design manufacturing optimization through hierarchical manufacturing strategy and clinical feedback closed loop. The application of the system shows that it can significantly shorten the product development cycle, improve the fitting degree of the last, and effectively solve the secondary injury problem caused by unsuitable shoes for patients with foot deformity. The technology system not only breaks through the bottleneck of large-scale production of personalized medical products, but also establishes a medical engineering cross innovation paradigm by transforming clinical pathology cognition into quantifiable engineering parameters. In the future, it can further integrate biosensor and deep learning technology, expand to gait correction, exercise rehabilitation and other scenes, and promote personalized medical treatment from theoretical research to industrialization.

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